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Development of Low Pressure and Low Energy Sprinkling Nozzles

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ABSTRACT

Existing options of efficient irrigation technologies in India are not widely adopted. Some of the major reasons are majority of the cropping area under field crops, small and fragmented land holdings and limitations of users to make high initial investments. This has restricted the adoption of efficient irrigation technologies for high valued crop. Whereas majority of the small and marginal farmers still practice surface methods of irrigation incurring not only huge wastage of water but also diesel and electric energy used for pumping when groundwater is used for irrigation. Considering conditions at small farms an attempt has been made to develop low cost water and energy efficient pressurized irrigation device, which can operate at an operating pressure less than 1.0 kg/cm^2 at its nozzle head. LEPA nozzle developed by A&M Texas is one of such attempt which operates between 0.07-0.35 kg/cm^2. Some of the concepts of LEPA development have been taken into consideration, besides considering priorities of small holders in developing a Low Energy Water Application (LEWA) device. This paper discusses the target group for whom development have been initiated, experiences and lessons at different developmental stages and basic criteria adopted for the development of LEWA device.

Application efficiency and uniformity of water application of an irrigation method are important factors, which affect the soil storage and distribution of irrigation water. The application efficiency is mainly affected by management; while the uniformity of water application is mainly affected by system design. The different losses associated with the surface method of irrigation are: conveyance losses, runoff and deep percolation losses, and direct evaporation from wet soil surface. Whereas in case of pressurized irrigation systems, minimal or no conveyance losses occurs and controlled volume of water is applied uniformly through a specially designed emitting devices. Different types of pressurized irrigation nozzles are in use such as sprinkler, micro sprinkler, and drip. Sprinkler and micro irrigation systems have efficiency in the range of 65-80%. Whereas drip irrigation system has efficiency in the range of 85-95% and is generally recommended for use in high-value horticultural and plantation crops and not for closely growing crops due to higher system cost. The sprinkler system is suitable for almost all crops but does not provide as good a control over water application as the drip system does. Besides, excessive evaporation loss and high energy consumption are associated with the use of sprinkler system. Most of the commercially available sprinklers work satisfactorily in the pressure range of 1.5-4 kg/cm^2. In order to reduce the energy requirements, different modifications have been made in the design of sprinkler nozzle and different management strategies have been developed to suit the requirements of growers.

Perforated Pipe Sprinkler Irrigation Systems

This type of sprinkler system sprays water from smaller diameter holes (1.6 mm or less) drilled at uniform spacing along the top and sides of a lateral pipe. The water coming out from the holes produces a rain like pattern over a rectangular strip. The size and spacing of the holes are chosen in such a way that water is uniformly distributed between adjacent lines of perforated pipe. The water spread (area of coverage) from this type of system increases as the pressure increases and operates effectively at pressures between 0.35 - 2.10 kg/cm^2 (Keller & Bliesner, 1990). As the minimum application rate from perforated pipe is 13 mm/hr, they can be used only on coarse textured soils. These types of system are widely used in lawns and are now obsolete in agricultural irrigation.

Hose Fed Sprinkler System

This type of system employs hose pipes to supply water to individual small sprinklers, which are operated at a pressure as low as 0.35 - 0.70 kg/cm^2 (Keller and Bliesner, 1990). These systems also produce relatively uniform water application when sprinklers are moved in a systematic grid pattern with sufficient overlap. These

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systems are generally used in home gardens and turf irrigation, and are not in use for agricultural irrigation as they are labour intensive.

In order to reduce the energy requirement, Lyle and Bordovsky (1981,1983) modified the design of existing sprinkler nozzle and developed management strategies for efficient utilization of available water. Their device is popularly known as Low Energy Precision Application (LEPA) system.

LEPA Irrigation System

The LEPA Irrigation system was developed by A&M Texas, USA, replacing the sprinkler nozzles by "drop tubes" making it suitable to operate at low pressure (3 – 12 m of water column) at the nozzle head (Bordovsky et.al., 1992). It reduces energy requirement in irrigation with acceptable precision in water application. Water is delivered to crops from center pivot or linear move irrigation systems. The irrigation-tillage management system with alternate ridge and furrows with tied ridging can better utilize available water resources. LEPA nozzles are positioned close to the ground, usually not more than 18 inches above the furrow. Nozzles are adjustable, allowing for three basic modes of operation: bubble, spray and chemigation. An additional method of water delivery for a LEPA system is the LEPA sock. The sock is attached to a drop hose and lies on the ground between the rows. The LEPA equipment discharges water through drop tubes very near to (50 to 75 mm above the soil surface) or at the soil surface into either every furrow or alternate furrows at a low pressure from 0.07-0.35 kg/cm^2. By discharging water near the field surface the spray evaporation losses are reduced. Because of the low application pressure of LEPA nozzle, water is applied over a relatively small area causing high application rates fro short duration. Since the high application rates quickly exceeds infiltration rates, successful irrigation with this system depends on temporarily storing some water on the soil surface until it infiltrates into the soil. Lyle and Bordovsky (1981) used diked furrow to retain the discharge obtained from the LEPA device. But the applicability of these systems in Indian conditions is not possible as these systems are highly mechanized and large systems.

LEPA system has been successfully tested in different crops, namely, wheat (Schneider and Howell, 1997), cotton (Bordovsky *et al.*, 1992), corn (Lyle and Bordovsky, 1995; Schneider and Howell, 1997), Sorghum (Bordovsky and Lyle, 1996; Schneider and Howell, 1997).

A LEPA type micro sprinkler

A LEPA type micro sprinkler was developed to provide irrigation in vegetable, horticultural, ornamental plants and lawns (Visalakshi *et al.*, 2002). The rotating sprinkler head was made of a small piece of 12mm/8mm diameter good quality LDPE pipe, plugged at both ends. The length of the unit was 8 cm for 12 mm and 5 cm for 8 mm pipe. Holes of 1 mm diameter were drilled on opposite sides of the pipe and pivoted at the centre to stand on a stake. The discharge rate was reported to be 30 to 45 lph at an operating pressure ranging from 0.3-1.0 kg/cm^2 for different pipe diameters. The wetted diameter ranged from 210-230 cm when nozzle rotated at a height of 30-90 cm above the ground. This system does not have any sophisticated components, is free from clogging, provides better sub-surface uniformity of water, avoids any losses due to percolation or runoff, facilitate the use of fertilizers and herbicides and most importantly, it has considerably low initial investment and operational cost.

Development of Low Pressure Water Application (LPWA) device

In India farm holding sizes of majority of the farmers is very small, the average being 1.18 ha (Anonymous, Agriculturist online) and fragmented. Those having irrigation facility extensively practice surface irrigation in rectangular check basins of width varying between 6 to 8 m and length equaling the field length and generally being 2 to 4 times of the width. The cropping pattern in most areas comprises cereals, pulses, oilseeds etc. followed by vegetables and orchards. The economic condition of the small farmers does not permit them to purchase and operate high-pressure irrigation system. If motivated, they may adopt less expensive low-pressure systems, provided they meet the irrigation requirement.

Developmental Stages

Design of LPWA manifold

Similar to the concept of LEPA a manifold was designed and fabricated with following dimensions of its components: Manifold diameter = 2.5 cm; Manifold length = 6 m; Number of drop tubes per manifold = 4; Diameter of the drop tube = 12.5 mm

The manifolds were tested operating two of them together. The average discharge of each drop tube was 0.48 and 0.60 lps at lateral inlet pressure of 0.5 and 0.75 kg/cm^2, respectively. The coefficients of variation (CV) in all the cases were below 10 % (Table 1). Some of the major limitations observed were weight of the manifold

Table 1. Discharge variation in Drop tube

Outlet no.	Avg. Discharge (lps) at operating pressure 0.75 kg/cm^2		Avg. discharge at operating pressure 0.5 kg/cm^2	
	Manifold 1	Manifold 2	Manifold 1	Manifold 2
1	0.65	0.58	0.52	0.47
2	0.58	0.60	0.46	0.48
3	0.57	0.59	0.44	0.48
4	0.61	0.60	0.50	0.49
Average	0.60	0.59	0.48	0.48
CV	0.059	0.016	0.075	0.019

and sagging due to weight of water. Testing at different angles revealed that at an angle of 45° from horizontal, the water throw distance was maximum but it caused erosion.

Design of Water Distribution Devices

A 2.54 cm diameter and 10cm long pipe section was divided into a number of sections. The cross-sectional area of each section at the inlet was kept equal whereas it was varied at outlet assuming that varying cross-sectional area and number of sections will prevent concentration of flow at one point. The equal cross-sectional area at the inlet enables equal quantity of water through each section. Varying cross-section at the outlet helps in achieving different throw distance and thus covering more width. With the above concept the device having 4, 5, 6 and 7 sections were developed and tested (Table 2).

Table 2. Effect of cross-sectional area on throw distance from riser

Throw distance, m	Number of cross sections			
	4	5	6	7
Minimum	0.9	0.9	0.9	1.0
Maximum	1.8	1.9	1.9	2.1
Total width of coverage	0.9	1.0	1.0	1.1

Testing revealed that the nozzle having 7 sections, performed better. The testing was done for different cross-sectional area of the outlet at a fixed inlet area. Different configurations were generated by varying the ratio of outlet to inlet cross sectional area (Table 3).

Different configurations were tested for throw distance at different pressures, keeping the maximum pressure at 0.4 kg/cm^2. Among the different configurations, the configuration "A" was found to perform better (Table 4).

Design of perforated pipe system

Though the developed nozzles could distribute water to larger width, soil erosion occurred due to lack of uniformity in the flow distribution. Also it was found that dividing the total cross sectional area of pipe into 7 sections was inadequate to reduce the droplet size. Subdivision beyond was infeasible manually. As an alternative, hole diameter was made smaller (0.75 mm) on the 7.5 cm diameter PVC pipes in three rows with the angle between two adjacent rows at 22.5°. Discharge through individual holes and also the total discharge of the pipe was measured at different pressures (0.2 to 0.6 kg/cm^2). This system was compared with traditional method of irrigation. Field plots of 6m widths and 20m lengths were prepared and properly leveled. It was divided into (2 x 2) m square grids and elevation was

Table 3. Cross sectional area ratios for three different sections

Configuration	Ratio of outlet to inlet cross sectional area for 7 sections						
	1	2	3	4	5	6	7
A	0.16	0.33	0.37	0.41	0.61	0.76	4.23
B	0.16	0.46	0.53	0.60	0.82	0.94	3.50
C	0.26	0.49	0.55	0.51	0.82	1.00	3.32

Table 4. Throw distance as a function of pressure

Pressure, kg/cm^2	Throw distance of different nozzle configurations having 7 sections					
	A		B		C	
	Min	Max	Min	Max	Min	Max
0.10	0.6	1.65	0.7	1.60	0.7	1.60
0.25	1.05	2.75	1.0	2.85	1.16	2.55
0.40	1.35	4.30	1.43	4.05	1.53	3.85

recorded at each grid points for computation of the leveling index. Moisture contents at different depth (15, 30, 45, 60, 75 and 90cm) both at the head and tail end of the plots were measured before and after irrigation to ascertain the depth of infiltrated water (Tables 5 and 6).

Table 5. Moisture variation under traditinnal method

Soil depth, (cm)	Moisture Content after Irrigation Head end	Tail end
15	22.3	20.2
30	24.2	21.5
45	21.2	18.5
60	20.1	20.3
75	20.6	17.5
90	21.7	19.0

Table 6. Moisture variation with LPWA

Soil depth, (cm)	Moisture Content after Irrigation Head end	Tail end
15	22.3	20.2
30	24.2	21.5
45	21.2	18.5
60	20.1	20.3
75	20.6	17.5
90	21.7	19.0

The moisture content distributions by perforated pipe system were found better than the traditional method of irrigation. One of the major drawbacks observed was lodging of crop after 15 to 20 minutes of irrigation. This may be due to continuous application of water at one point. Due to this reason, effort for its further development was not made and the device was considered 'unsuitable'.

Development of Low Energy Water Application (LEWA) Device

On the basis of experiences with the developed LPWA, it was appropriate to develop a rotating device similar to sprinklers that can distribute water uniformly in various directions, does not cause soil erosion and crop lodging. The proposed device should satisfactorily work at low pressure to fulfill irrigation objectives and be cost effective. As stated by Hillel (1989), an advanced irrigation system for small holders should be: low cost, have simplicity in design and operation, reliability, longevity, few manufactured parts that must be imported, easy maintenances and low energy requirements. Considering all these factors a simple and less expensive Low Energy Water Application (LEWA) device was developed, which could simulate rainfall similar to the conventional sprinkler nozzles.

Design Criteria of LEWA

Based on the experiences and lessons learnt while developing the low-pressure water application device, following points were considered (Singh *et al.*, 2004):

- If water droplets/ jets strikes same location of the soil surface repeatedly, there is every possibility of soil erosion. To avoid this there is a need to develop rotating mechanism that will prevent the water droplet to continuously strike the same point.
- When the moment of momentum of outflow from a control volume is different from that of the inflow, a torque develops in the control volume. This torque causes the pipe to rotate if it were to be free to do so. A rapidly rotating jet breaks up into smaller water droplets and reduces chances of soil erosion or sagging of crops. However, finer droplets are more affected by wind and hence more evaporation and drift losses occur.
- The objective of irrigation is to apply required depth of water uniformly over an area. Thus if number of holes (more than two) are made on a pipe section, the water jets /droplets will cover larger number of points simultaneously resulting in more uniform

application of irrigation water. As the number and size of holes is changed, the rotation speed also gets changed, which ultimately affects the application pattern.

- The trajectory angle of the sprinkler influences the water application pattern and hence application uniformity. In absence of air drag, a 45° trajectory angle would give the maximum wetted diameter for a given nozzle and pressure. Due to air resistance encountered by water jet, the trajectory angle at which maximum throw is achieved is generally less than 45°. Most of the sprinkler manufacturers have adopted 27° as "standard" trajectory angle.

The design of water application device considered here consists of rotating mechanism along with the design of water application component. Important factors which were taken into consideration were:

(a) Length of the rotating device;

(b) Size and number of holes;

(c) Arrangement of holes (Location/Spacing /trajectory angle of the holes).

Development of Prototype of LEWA device

To develop the prototype PVC pipe of 25mm diameter was used to develop a *"Tee"* shape device having equal number of holes on opposite sides on 6 rows. Different combinations of factors as mentioned above were also considered in developing the prototype (Fig. 1) for testing in the laboratory.

Different combinations tried were;

(a) Length of the rotating device: 10, 20, 30 and 40 cm,

(b) Size of holes: 0.75, 1 and 1.5 mm, and

(c) Location (trajectory angle) of the holes: One central row with 0° angle with horizontal) initially and five rows with different trajectory angles later.

A socket and bush arrangement was made (Fig. 2) through which the device could be installed on a riser pipe.

Fig. 1: The view of the low energy water application device

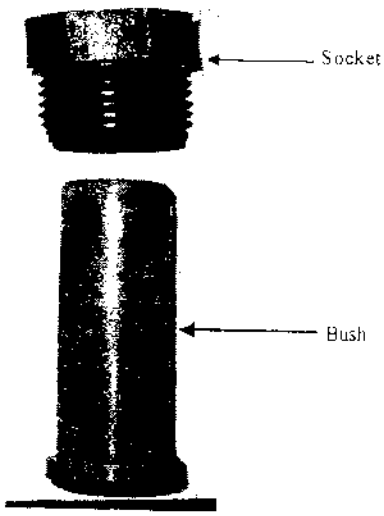

Fig. 2: Rotating Mechanism of LEWA (Socket and Bush)

Effect of different parameters on device performances

Device length

Initial testing was done with device lengths of 10, 20, 30 and 40 cm having equal number of holes arranged in a single line (hole diameter 0.75 – 1.5mm). The device started rotating at 0.2 kg/cm² in few cases. There was no rotation when the device length was less than 10 cm for any of the hole sizes whereas when the length was 10 cm or more the device rotated. It was also observed that throw diameter increased as the arm length increased. Hence, for designing purpose the minimum device length selected was 30 to 40 cm.

Hole size

To evaluate the effect of hole diameter on water application pattern, different hole diameters were made (0.75, 1.0 and 1.5 mm). In general, as the diameter of the hole increased application rate also increased. A peak was observed in every case which was highest in case of 1.5 mm diameter hole. Choking of holes were observed while operating the device, hence, for design purposes hole sizes 1 mm or greater was preferred.

Number of holes

When the spacing of holes was reduced for a constant and arm length, the water application rate increased due to increase in the number of holes. Different combinations in this case were tried but most important was the required discharge one likes to have from the device.

Arrangement of holes

Initially, holes were made in a single line throughout the pipe length placed parallel to horizontal at the centre of the device. Subsequently, holes were spread in five rows (based on trajectory angles). For the latter case, the throw distance was higher and water was distributed more evenly. Hence, it was decided to consider arranging holes in more than one line.

Finally, following dimensions to initiate the design the prototype of LEWA device was considered;

(a) Length of device = 30 cm (L1) and 40 cm (L2).

(b) Hole diameter = 1 mm (D1), 1.5 mm (D2) and 2.0 mm (D3).

(c) Hole Numbers = 15 numbers each side (total 30 holes)

(d) Arrangement of holes = Arranged in five rows.

Several combinations of device have been tested for different discharge rates and throw diameters by varying the operating pressure (Table 7). It was observed that the discharge increased and throw diameter enlarged when the device length was longer. Throw diameter also increased with an increase in operating pressure and increase in hole sizes. Based on these observations, the 40 cm long device with 30 holes of 1.5 mm diameter arranged in two rows was found most appropriate.

CONCLUSIONS

The overall efficiency of the flow irrigation methods is very low in India. The efficiency can be substantially improved by adopting pressurized irrigation methods where the timing and quantity of water application can be controlled based upon the crop need. Improving efficiency also implies the possibility of using the same available water for irrigating larger areas. The impediments in adopting pressurized irrigation in India are the large population of resource poor farmers, lack of technical skill needed to operate and maintain such systems and a generally poor situation and uncertainty of energy availability to the farmers. All these impediments can be properly addressed through the development of low-pressure micro-irrigation systems that does not require continuous power supply, are comprehensible systems requiring much less technical

Table 7. Discharge and throw diameter at different operating pressures

Specifications	Trial No.	Discharge (lps) at different pressures (kg/cm²)			Throw diameter (m) at different pressures (kg/cm²)		
		0.2	0.4	0.6	0.2	0.4	0.6
L1D1*	I	0.104	0.160	0.176	4.0	5.5	6.5
	II	0.112	0.164	0.188	4.0	6.0	6.5
	Average	0.108	0.162	0.182	4.0	5.75	6.5
L1D2	I	0.204	0.272	0.282	4.5	6.0	7.0
	II	0.214	0.288	0.292	4.5	6.0	7.5
	Average	0.210	0.280	0.288	4.5	6.0	7.25
L1D3	I	0.490	0.644	0.768	5.5	6.0	7.0
	II	0.444	0.576	0.600	5.0	6.5	8.5
	Average	0.468	0.610	0.684	5.0	6.25	7.75
L2D1	I	0.128	0.164	0.188	5.0	6.0	7.0
	II	0.120	0.168	0.182	4.5	6.5	7.0
	Average	0.124	0.162	0.186	4.75	6.25	7.0
L2D2	I	0.236	0.300	0.356	4.5	6.0	7.0
	II	0.212	0.276	0.292	5.0	6.5	8.0
	Average	0.224	0.288	0.324	4.75	6.25	7.5
L2D3	I	0.476	0.566	0.716	5.5	7.0	7.0
	II	0.426	0.548	0.656	6.0	8.0	8.5
	Average	0.452	0.555	0.686	5.75	7.5	7.75

skill to operate and maintain and are suited to the small farm size in India. In the reported study, first a low-energy (hence, a low-pressure) micro-irrigation system was developed and evaluated. The system could operate satisfactorily at an operating pressure ranging between 0.4-0.6 kg/cm^2 (at its nozzle head) in comparison to conventional sprinklers, which need not less than 1.5 kg/cm^2 of operating pressure at their nozzle head. The required pressure can be generated by an over-head water tank fixed 4 to 6 m above the ground level. The tank may be filled when power is available. The size of the tank or its numbers can be decided based on the area to be irrigated. The average throw diameter and the average discharge of the system were 6.1 m and 0.332 lps, respectively.

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